Accelerator Physics Issues of a Very Large Hadron Collider

W. Chou

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

June 1997

Published Proceedings of the 1997 Particle Accelerator Conference PAC 97,
Vancouver, Canada, May 12-16, 1997
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ACCELERATOR PHYSICS ISSUES OF A VERY LARGE HADRON COLLIDER

W. Chou, Fermilab,* P.O. Box 500, Batavia, IL 60510, USA

Abstract

A Very Large Hadron Collider (VLHC) was proposed for the post-LHC future.[1] This paper gives a quick survey of a number of accelerator physics issues based on the information obtained from a parameter spreadsheet SSP.[2] The main technical challenges to build such a machine appear to be: the large number of events per crossing (in hundreds), enormous beam stored energy (equivalent to tens tons of TNT), ground motion (which is particularly harmful when the synchrotron frequency is in the sub-Hertz range), small dynamic aperture (due to long filling time), fast growth of the resistive wall instability (in a fraction of one turn), low threshold of the single bunch transverse instability (due to big machine size), strong synchrotron radiation (at a level close to the LEP) and short radiation damage lifetime, etc.

Possible solutions to some of these problems will also be discussed.

I. INTRODUCTION

The VLHC is really very large in the low field approach. Although a coherent parameter list is yet to be developed, this paper will base its discussions on the following assumed "Level 0" specifications:

\[
\begin{align*}
\text{Energy per beam } E & = 100 \text{ TeV} \\
\text{Luminosity } & = 1 \times 10^{35} \text{ cm}^{-2} \text{s}^{-1} \\
\text{Collision} & = p-p \\
\text{No. Detector} & = 1 \\
\text{Circumference} & = 10^6 \text{ meters}
\end{align*}
\]

Because the interaction cross section is approximately proportional to \(1/M^2\), where \(M\) is the equivalent parton beam energy, the luminosity should go as \(E^2\). Anything below \(10^{35}\) may be difficult to justify for a 100 TeV machine.

The physics of \(p-p\) and \(\bar{p}-p\) is similar at multi-TeV region. But \(p-p\) is easier to reach high luminosity. Besides, \(\bar{p}\) may be just too expensive to fill up a megameter ring.

Starting from these top level parameters, one can generate their derivatives by running a spreadsheet. One such program is the SSP. It was originally written for the former project SSC, but can easily be modified to serve the VLHC. The next section will discuss a number of accelerator physics issues based on the output of this program.

*Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the U.S. Department of Energy.

II. SELECTED ISSUES

A. Events per crossing

The number of events per crossing has a Poisson distribution. The average number \(n\) is:

\[
\begin{align*}
n = \mathcal{L} \sigma_{\text{inel}} S_b
\end{align*}
\]

in which \(\sigma_{\text{inel}}\) is the inelastic \(pp\) cross section, and \(S_b\) the bunch spacing. The value of \(\sigma_{\text{inel}}\) at 200 TeV center-of-mass energy is unknown. If the scaling law in the lower energy regions is employed, it could be estimated at about 150 mb. Thus, the only knob to reduce \(n\) is by reducing \(S_b\), i.e., increasing the number of bunches. But even at a 16 ns bunch spacing, the number of events per crossing could still reach about 300! This must be a serious challenge to the detector design.

B. Beam stored energy

This is one of the primary concerns. For \(\mathcal{L} = 10^{35}\), \(S_b = 16 \text{ ns}, \beta^* = 0.3 \text{ m}, \text{and } \epsilon_{\text{n}}(95\%) = 24\pi,\text{ the current is about 0.6 A per beam. The stored energy of the two beams would be about } 400 \text{ GJ, which is equivalent to 90 tons of TNT! Any accidental beam loss could be a catastrophe.}

C. Ground motion

This is another primary concern for a machine of this size. It has two effects:

1. Relative movement of the magnets:
   This may be caused by tides, seismic effects, ground water level changes, etc., which could lead to misalignment and mis-steering and result in an aperture problem.

2. Resonance with the synchrotron frequency:
   The small slip factor (\(3 \times 10^{-5}\)) and low revolution frequency (300 Hz) lead to a very low synchrotron frequency (fraction of 1 Hz). This would make it vulnerable to external perturbations, such as the ground motion, which has large components in this low frequency range.

D. Filling time and dynamic aperture

Assuming two rings in the Tevatron tunnel as the injector, each capable to deliver 2.5 TeV protons (using 10 Tesla dipoles), cycle time 200 seconds. Then the filling time would be over 9 hours!

Such a long filling time would pose a threat to the dynamic aperture at injection. The big dynamic range of the beam energy (from 2.5 to 100 TeV, a factor of 40) would imply that the field quality at injection could not be very good. Assume the error field be similar to that of the SSC magnets. Then, scaled from the SSC simulation results, the dynamic aperture would shrink to less than 1 \(\sigma\)!